2.13 CM/CCM

CM

Brawler simulates an ECM environment which has a profound effect on many of the major components of the model including AI radars, GCI radars, missile guidance, and voice communications.

Self Screening Jammers (SSJ)

Any member of the engaging flights in the simulation can be specified as an SSJ by equipping that aircraft with a pod containing at most three jammers (noise or deceptive). Each jammer maintains a fixed user-specified orientation with respect to the aircraft and emits jamming power into a portion of the sky specified by an azimuth width and an elevation width.

Stand Off Jammers (SOJ)

SOJs are peripheral entities. Although they are equipped with a pod containing up to three noise jammers (similar to an SSJ), they move as point masses in repetitive patterns consisting of a series of straight line segments. Because they normally patrol at large distances from the engagement, they are not allowed to be detected as isolated aircraft. Any need for a more intelligent and capable SOJ entity may be met by equipping regular aircraft with appropriate SSJ pods.

Expendables

Brawler simulates the effects of expendables on the performance of missiles. Expendables are launched against specific missiles and may have one of three effects on a missile (see Section 4.1.3.2): the missile may be made to go ballistic shortly after employment, it may be made to fly out normally but have the endgame Pk degraded to reflect the effects of the expendable on the missile guidance, or it may be made to guide on the signal centroid between the expendable and the target aircraft. The trajectory of expendables after they are launched is modeled explicitly. Trajectories currently available include a free-falling, exponential decay to a vertical terminal velocity and a constant range, constant elevation tow behind the launching aircraft.

Explicit modeling of expendable signals is available only with flares and towed decoys. In each case, the expendable produces a signal which is treated the same as any other signal by the seeker. Depending upon the timing and relative geometry of expendable and aircraft signals, the seeker may produce separate observations of expendable and aircraft or it may be unable to resolve the objects and may produce a single observation at the centroid of the signals. Depending on the observations, the missile may guide on the centroid between the expendable and aircraft, it may guide only on the expendable signal, or it may ignore the expendable and continue to guide only on the target signal.

Flares

Each aircraft in Brawler may carry a user-specified number of flares for use against IR missiles. Each flare type is described in input files as to its type of countermeasure method and its trajectory behavior after deployment. Flares may employ either ballistic, Pk degrade, or centroid methods for defeating a given type of IR missile and may employ different methods for different missiles (ref: sections 4.1.3.1.1 - 4.1.3.1.3). However, at present, there is no direct affect on avionics (such as IRSTS).

Chaff

Each aircraft may carry a user-defined number of chaff bundles. Each type of chaff is described in data files regarding the wavelengths for which it is effective, its persistence, etc. Chaff may employ either ballistic, Pk degrade, or centroid methods for defeating a given type of RF missile and may employ different methods for different missiles (ref: sections 4.1.3.1.1 - 4.1.3.1.3). However, at present, the only affect on avionics is the extent to which avionics are used to guide missiles.

Towed Decoys

Each aircraft may carry a user-specified number of decoys for use against RF missiles or radars which may be dropped or towed by the aircraft. Each decoy is described in input files as to its trajectory type (if dropped) or position relative to the aircraft (if towed) and its signal amplification properties. The towed repeater expendable attempts to generate noise which mimics the reflected return from the aircraft from which it is ejected. It does so by measuring the incoming signal and generating an output signal appropriate to some assumed cross section of the aircraft.

Decoys may employ either ballistic, Pk degrade, or centroid methods for defeating a given type of RF missile and may employ different methods for different missiles (ref: sections 4.1.3.1.1 - 4.1.3.1.3). However, at present, there is no direct affect on avionics.

Techniques / Effects

Weapons - General

Expendables can have one of three effects on missiles: to degrade the probability of kill, to draw off a missile into a ballistic state, or to cause the missile to guide on the signal "centroid" of the expendable and the target aircraft. In the current implementation, the effect of an expendable on a missile is explicitly declared through the use of the input data files. Aside from this, the effects depend only on the characteristics of the expendable, event timing and geometry.

Ballistic

The ballistic effect is modeled by assuming that the draw-off mechanism becomes ineffective if the expendable is deployed with too little time-to-go. A one-time random draw is made against a probability determined from the characteristics of the expendable and the estimated time-to-go until missile fuzing at the time of the expendable ejection. The probability is determined as follows:

$$P_{blstc} = P_{draw}\, \mathit{border}(T_{go}-T_{min}, T_{width}) \qquad [2.13\text{-}1]$$

where we define:

P_{blstc} = The probability that the expendable will cause the missile to go ballistic.

P_{draw}	=	The probability that the missile will be drawn into a ballistic state given an optimal situation. (Expendable characteristics data item)
T_{go}	=	Estimated time-to-go until fuzing when the expendable is deployed.
T_{min}	=	A time-to-go until fuzing before which an expendable must nominally be employed if it is to be effective in making the missile go ballistic. (Expendable characteristics data item.)
T_{width}	=	Half-width of the window about the optimal time of release. (Expendable characteristics data item.)

Pk Degrade

This effect is dependent on the time of launch and the missile/target/expendable geometry. A running score of the degradation is kept as the missile flies towards its target, and the P_k at fuzing is degraded by a function of this score. In the current implementation, the degradation is a function of θ_{RMS}, the RMS angle between the LOS to the target (from the missile) and the LOS to the expendable. The sum used to compute θ_{RMS} is accumulated during each missile flyout. At the time of fuzing this accumulated score is used to degrade the P_k as follows:

$$P = P_k(1 - P_d P_{max})$$

$$P_d = \mathit{cauchy}(T_{flight} - T_{opt}, \tau)\,\mathit{ramp}(0.0, \theta_{RMS}, A_{max})$$

where we define:

P	=	The probability of kill degraded by expendable effect.
P_k	=	Unadjusted P_k in absence of expendable.
P_d	=	The efficiency, relative to the maximum possible, of the degradation due to the expendable.
P_{max}	=	The maximum percentage of the P_k that can be degraded. (Expendable characteristic data item)
T_{flight}	=	The time of flight for the expendable.
T_{opt}	=	The optimal time of flight for this expendable. (Expendable characteristic data item.)
τ	=	A time constant. (Expendable characteristic data item.)
A_{max}	=	The largest value that the normalized score can attain. This is related to the maximum angle at which the expendable can affect the missile.

Centroid

The intent of the centroid effect is to have the missile seeker track a point in space which is determined by the weighting of the signal from the decoy and the signal from the target return (the signal “centroid”). The effect on missile guidance then follows naturally.

The repeater expendable attempts to generate noise which mimics the reflected return from the aircraft from which it is ejected. It does so by measuring the incoming signal and generating an output signal appropriate to some assumed cross section of the aircraft. We will denote this cross section as σ_x. The quantity of interest in determining the centroid effect is the ratio of signal from the target to signal from the expendable. Two cases apply: (a) the expendable is saturated and cannot generate enough signal appropriate to the assumed cross section and (b) the expendable is not saturated.

The effective centroid is determined as follows. Define

R_t	=	Range vector from missile to target.
R_j	=	Range vector from missile to decoy.
R_{eff}	=	Effective range vector from missile to target degraded by jamming.

Then define the effective range vector (centroid) as a weighted sum of the vectors to the actual target and to the decoy:

$$R_{eff} = W\, R_t + (1-W)\, R_j \qquad [2.13\text{-}2]$$

where $0 < W < 1$ and:

$$W = \frac{S_t}{S_j + S_t} \qquad [2.13\text{-}3]$$

This formulation for W has the property that for zero jammer power, R_{eff} is at the actual target and for equal signal contributions from target and jammer, R_{eff} is at the midpoint of a line between target and jammer. The calculation of the ratio of target to jammer signal is treated for each case.

Saturated Repeater

In the case of an active radar missile, an effective target position can be derived from the following analysis. Define the following variables:

r_t	=	Unit vector from missile to target.
R_t	=	Range vector from missile to target.
R_t	=	Range from missile to target.
r_j	=	Unit vector from missile to decoy.
R_j	=	Range vector from missile to decoy.
R_j	=	Range from missile to decoy.
σ_t	=	Target cross section (function of geometry).
R_{eff}	=	Effective range from missile to target degraded by jamming.
S_j	=	Signal at seeker due to decoy.
S_t	=	Signal at seeker due to skin return.

The ratio S_t/S_j can be written as:

$$S_t \big/ S_j = \frac{Q\sigma_t R_j^2}{E(\theta,\varphi) R_t^4} \qquad [2.13\text{-}4]$$

where E(h,u) is the effective radiated power (saturated) of the decoy as a function of azimuth and elevation to the radar. With no loss of generality we can write E(h,u) as:

$$E(\theta,\varphi) = E_m g(\theta,\varphi) \qquad [2.13\text{-}5]$$

where E_m is the maximum effective radiated power and g is the transmitter gain function whose maximum value is 1. Q contains attributes of both the radar and the jammer. It can be computed with the addition, to the existing data sets, of a single parameter, R_{bt}. We define R_{bt} as follows. Consider a 2m^2 target and the decoy to be co-located, and orient the decoy for maximum gain, g=1. R_{bt} is the range to this configuration for which the ratio (S_t/S_j) is the same as that which will produce a 50% probability of skin detection for the missile radar, $(S/N)_{50}$. Equation 3 then becomes:

$$(S/N)_{50} = \frac{Q\sigma_o}{E_m R_{bt}^2} \qquad [2.13\text{-}6]$$

where σ_o is 2m^2. Solving Eq. 5 for Q and substituting for Q in Eq. 3 yields:

$$S_t \big/ S_j = (S/N)_{50} \frac{\sigma_t}{\sigma_o} \frac{R_{bt}^2 R_j^2}{R_t^4 g(\theta,\varphi)} \qquad [2.13\text{-}7]$$

This equation undergoes slight modification for the case of a semi-active missile. The complications arise from the fact that the signal power at the missile is generated by a stand-off platform not at the missile location. First, the definition of R_{bt} requires the additional constraint that the illuminator must be co-located with the missile for its evaluation. Also, the term R_t^4 in the denominator is replaced by,

$$R_t^4 \rightarrow R_i^2 R_t^2 \qquad [2.13\text{-}8]$$

where $\mathbf{R}_i$ is the range from illuminator to target. Finally, the target cross section must be replaced by the bistatic cross section.

Unsaturated Repeater

The unsaturated case is much simpler since the repeater is mimicking the target (except that the assumed cross section may be incorrect and the range to the detector is different). Also, the jammer signal is degraded by both the jammer receiver and transmitter gains. The resulting expression for signal to jammer power in the active case is:

$$S_t/S_j = \frac{\sigma_t}{\sigma_x} = \frac{R_j^4 \big/ R_t^4}{g(\theta,\varphi) h(\theta,\varphi)} \qquad [2.13\text{-}9]$$

where h is the receiver gain function and:

$$S_t \Big/ S_j = \frac{\sigma_t}{\sigma_x} \frac{R_j^2 \big/ R_t^2}{g(\theta,\varphi)h(\theta,\varphi)} \qquad [2.13\text{-}10]$$

for the semi-active radar case.

RF

At the most basic level, jamming power affects the signal-to-noise ratio used to determine if a detection has occurred. When the radar beam sweeps across a target, the total jamming power from all sources in the main lobe at that time is calculated. This jamming power then contributes to the total noise for the signal-to-noise calculation. If, based on the signal-to-noise, no skin detection is achieved, a jammed detection is declared whenever the jamming power exceeds the threshold ratio relative to noise plus clutter. If the radar is in single target track mode when the jammed detection occurs, or if the radar locks up on a jam strobe, the radar enters the angle-on-jam (AOJ) mode in which lock is maintained based on angular information. For aircraft equipped with TWS radars, aircraft in the track bank are denoted as AOJ targets if their last detection was in fact a jam strobe. For all types of radar, the designation of an AOJ target affects the launch criteria for missiles.

Noise Jamming vs Avionics

At the most basic level, jamming power affects the signal-to-noise ratio used to determine if a detection has occurred. When the radar beam sweeps across a target, the total jamming power from all sources in the main lobe at that time is calculated. This jamming power then contributes to the total noise for the signal-to-noise calculation. If, based on the signal-to-noise, no skin detection is achieved, a jammed detection is declared whenever the jamming power exceeds the threshold ratio relative to noise plus clutter. If the radar is in single target track mode when the jammed detection occurs, or if the radar locks up on a jam strobe, the radar enters the angle-on-jam (AOJ) mode in which lock is maintained based on angular information. For aircraft equipped with TWS radars, aircraft in the track bank are denoted as AOJ targets if their last detection was in fact a jam strobe. For all types of radar, the designation of an AOJ target affects the launch criteria for missiles.

Noise Jamming vs Missiles

Both semi-active radar seekers and active radar seekers are affected by noise jamming power entering the main lobe of the missile seeker during flyout. Jamming power entering the seeker sidelobes is not considered. Generally, the ECM effects are not dependent upon the power level of the noise at the seeker; the assumption being made is that the jammer always has sufficient power to be effective. Semi-active and active radar seekers are only affected by jamming when they are on. Missiles in a command guided phase will not be directly affected by noise jammers, although jamming may degrade the quality of their guidance data by affecting the launching platform's radar. Semi-active seekers guiding on intermittent TWS illumination will only be affected by jamming during the periods when the target is actually illuminated, as the seeker is off at all other times.

The effect of generic noise jamming is to mask the detection of all other signals in the seeker field of view. In addition, active radar seekers will not be able to make range or range rate observations; they will only observe the azimuth and elevation of the jammer. If there are two or more jammers in the seeker field of view, the seeker will produce a single observation whose azimuth and elevation will be the centroids of the angles of all of the observed jammers. If a missile is already guiding on a clear track and noise jammers enter the seeker FOV, the missile will not switch targets. It will continue to guide on its selected target track. However, the track will not be updated by new seeker observations as long as the seeker is being jammed, so the quality of the missile's guidance data will degrade the longer it is jammed. Eventually, the track will disestablished and then purged, at which point the missile will begin to guide on the jammer, as this will be its only established track.

Pk-Degrade Noise Jamming Effects

None of the generic noise jamming effects described above applies to Pk-degrade jammers. All of the effects for Pk-degrade jammers are lumped together into a single factor that is used to adjust the Pk value of the missile at endgame. If the missile is jammed at any time by a Pk-degrade jammer, the Pk-degrade factor will be applied at endgame. Only the first occurrence of the Pk-degrade jamming is treated. Once it has been determined that a Pk-degrade factor will be used to modify a missile's Pk value, no other Pk-degrade jammers (noise or deceptive) will have any affect on that missile.

Deception (vs Avionics)

Given that deceptive (or smart) jamming is present in the beam when a radar sweeps across a target, the outcome of the detection opportunity is dependent on the type of smart jammer and the mode of the sweeping entity.

Anti-Detection

The anti-detection technique is also referred to as bin-masking or synthetic clutter. It is only effective if the radar is operating in scan, TWS, or spotlight mode. The possible effects are jam alarm and detection denial.

Basically, the radar is assumed to have a minimum threshold setting and the jammer a maximum power. The minimum threshold implies that synthetic clutter fails to work when the signal would be above the minimum gain signal and a jam alarm will result. Since this is a function of the return signal strength, there is an R^4 dependence on cross-section. The maximum jammer power constraint implies that the jammer will not be able to keep up with the signal at a certain range. This implies an R^2 dependence on cross-section.

Three regions of range-to-target are defined by R_l and R_h. For targets inside R_l, a probability of alarm, P_a, and probability of masking, P_m, are defined which are both small. Consequently this region usually generates burn-through detections. Between R_l and R_h, P_a is usually high and P_m is small; hence jam alarms are usually generated in this region. Outside R_h, P_a is usually small and P_m is usually large, hence detection masking usually occurs in this range region. Because these effects depend on signal strength, the ranges R_l and R_h are scaled by the appropriate powers of target cross section.

Anti-Lock

If the radar is in STT, then loss of lock is determined by a random draw using a probability of break-lock which is an attribute of the jamming device. This test can be performed only once while the radar is locked on a target and is performed at a user-specified time after lock is achieved.

Cross Polarization

If the radar is in STT mode and the target has a cross-poll jammer that is effective against the radar, a similar test is performed to determine whether loss of lock will occur at some predicted time. This test does not involve a random draw, but is based on the look-up tables of predicted breaklock times as a function of the geometry for specific jammer/victim radar pairs.

Range Gate Pull Off (RGPO)

If an AI radar antenna has swept a target which has a deceptive jammer with RGPO capability against that antenna, systematic errors in range or range rate resulting from the pulloff are reflected in the sweep results. Additionally, a breaklock may occur if the antenna is in STT mode.

If the sweeping radar is in TWS or spotlight mode, two effects are possible:

1. The radar's track of the target is completely purged.

2. The track is reset to represent target track state if RGPO or VGPO was not applied. This second effect comes from a model of a TWS which tracks both the target's signal and the deceptive signal as separate tracks. When the deceptive track is discontinued, the target track remains. It is reset using the covariance matrix of the deceptive signal's track. Errors consistent with the covariance matrix are added to the ground truth to yield the new target signal track.

Velocity Gate Pull Off (VGPO)

Same as RGPO except for track velocities.

Deception (vs Missiles)

A number of deceptive jamming techniques against missiles with semi-active and active radar seekers are captured at the effects level in Brawler.

Generic Anti-Missile

Generic anti-missile jamming captures the effect of ECM against semi-active and active missiles at a very high level. For a semi-active seeker, this technique captures the effect of ECM directed against the radar being used to illuminate the target. If a semi-active seeker picks up a generic anti-missile jammer, then a one test is made to see if the jamming is effective. The test consists of a random draw against the probability that the jammer will affect the launcher's radar. If the draw succeeds, the missile goes ballistic. The test is performed at a data driven time after missile launch.

An active radar missile can also be indirectly affected by ECM against its launcher if the ECM affects the command guidance updates being sent to the missile before its seeker begins making observations. In this case, a random draw is also done, and if it is successful, the data link is broken and the missile receives no more updates. In addition, a second random draw is performed against a probability of 50% and, if the draw is successful, the missile's estimate of target angular rate is rotated by 90°.

Cross Polarization

Deceptive P_k-degrade jammers have the same effect versus missiles as do noise P_k-degrade jammers. All of the effects of the jammer are lumped together into a single factor that is applied at missile endgame. Once a P_k-degrade jammer has been determined to have jammed a missile, no other P_k-degrade jammers (noise or deceptive) will have any effect versus the missile.

Pk Degrade

Deceptive P_k-degrade jammers have the same effect versus missiles as do noise P_k-degrade jammers. All of the effects of the jammer are lumped together into a single factor that is applied at missile endgame. Once a P_k-degrade jammer has been determined to have jammed a missile, no other P_k-degrade jammers (noise or deceptive) will have any effect versus the missile.

Swept Repeater Modulation

Swept repeater modulation is only effective against active missile seekers. If the target that the missile is guiding on is carrying a swept repeater jammer which is effective against that seeker, then the seeker's observations of the target will contain errors in azimuth and elevation due to the jamming. The magnitude of the errors and the time after the jammer is first observed at which the errors begin to occur are both data driven and depend upon attributes of both the jammer and the seeker.

Communications

Communications jamming is modeled by degrading the probability of successful message transmission under ECM conditions. The model assumes a stand-off entity which monitors channel usage and allocates jamming power resources to each channel as a function of long-term average use of that channel. As with SOJs, explicit entities are not represented to model communications jamming since they would not likely become players. However, if the need should arise, it would be straightforward to specify that a particular player or players must remain alive for communications jamming to continue.

CCM

<u>Weapons</u>

IR

CCM does exist in Brawler for IR missiles if so desired and specified by the user. The Infrared Counter-Counter Measure (IRCCM) algorithm is used only while the missile is still on the rail at the point of initial target acquisition (although making it also operate during missile flight would not be rigorous) and operates as follows:

a. First, the signal strength is totaled for each signal type (aircraft or expendable) contained within each track of each trackbank of the missile. Each track is then labeled as an aircraft or expendable depending on which type of signal has the greatest (absolute) value.

b. Second, if both aircraft and expendable tracks are present within the trackbank, all aircraft signals are filtered through a user-specified minimum-signal-for-acquisition vs line-of-sight-angular-rate relationship. The surviving aircraft signals of this test are scored on signal strength with the strongest being acquired by the seeker.

If only expendable tracks are present, the seeker will not acquire any signals. If only aircraft tracks are present, the seeker will acquire the strongest without subjecting it to the user-specified threshold discussed above.

2.13.1 Functional Element Design Requirements

2.13.2 Functional Element Design Approach

Design Element 13-1:

2.13.3 Functional Element Software Design

2.13.4 Assumptions and Limitations

2.13.5 Known Problems or Anomalies